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Basic Electricity

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Subject **Page**

Basic Electricity

Model: All

Production: All

OBJECTIVES

After completion of this module you will be able to:

- Understand electrical energy.
- Identify the various methods for producing electromotive force and understand the differences between each of them.
- Identify basic requirements and main components of a complete circuit.
- Understand the fundamentals that govern electrical flow in the various types of circuits.
- Understand Ohms Law and perform mathematical calculations using established formulas.
- Describe Alternating Current and Direct Current.

Basic Electricity

Electricity is defined as the movement of electrons from one atom to another. In order to understand electricity a basic explanation of the atom is needed.

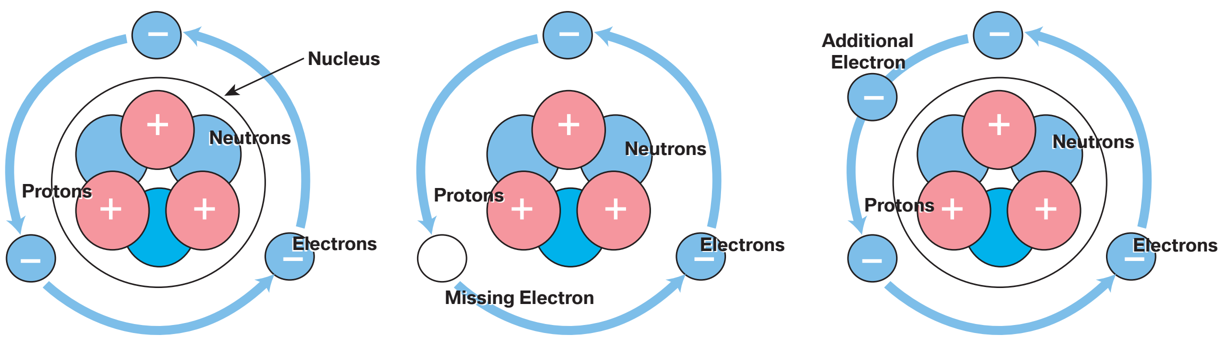
All matter is made up of molecules. An atom is the smallest particle to which a molecule can be reduced.

Atoms consist of:

Electrons - Negatively charged particles orbiting around a nucleus.

Protons - Positively charged particles in the nucleus.

Neutrons - Uncharged particles in the nucleus that stabilize the protons.



Balanced ion **Positive ion** **Negative ion**

An atom is balanced or displays a neutral charge when the number of protons and electrons are equal.

Through various means (e.g. A chemical reaction in the automotive battery) electrons are displaced from their normal orbit.

These displaced electrons attach themselves to other atoms, creating an unbalance in the number of electrons and protons in both atoms.

Atoms which loose or repel an electron become positively charged because of the greater number of protons. These atoms are called “Positive Ions”.

Atoms which pickup or gain extra electrons become negatively charged and are called “Negative Ions”.

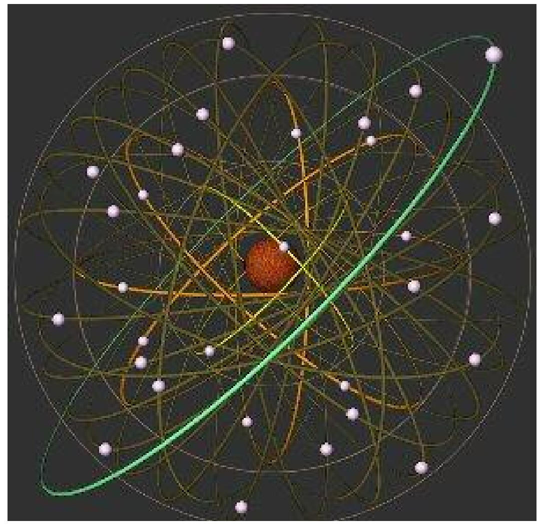
The negative ions will attempt to repel the extra electron and the positive ions will attempt to attract it.

The movement of free electrons from one atom to another is called electron flow or electric current flow.

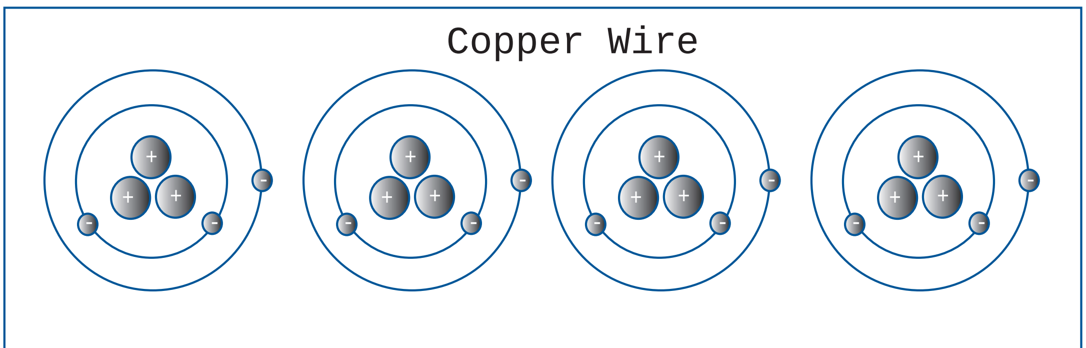
This flow of electrons does not mean that a single electron travels the entire length of the wire.

Electron flow is the movement of free electrons from atom to atom and the transmission of an electrical impulse from one end of a conductor to the other.

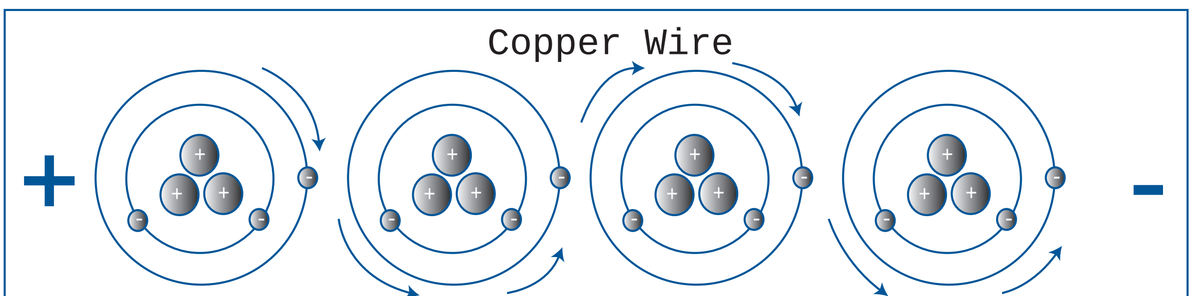
The constant unbalancing and rebalancing of the atoms takes place in less than one millionth of a second.



A single strand of copper wire contains billions of atoms



4 Atoms Shown
No Charge Applied To Wire



4 Atoms Shown
Charge Applied To Wire

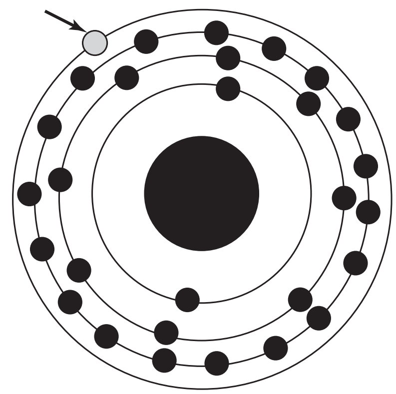
Conductors, Insulators and Semi-Conductors

Electrical properties of various materials are determined by the number of electrons in the outer ring of their atoms.

Conductors

Materials with 1-3 electrons in the atoms outer ring make it easy for electrons to move from atom to atom. Remember that the definition of current flow is the movement of free electrons from one atom to another. The electrons in the outer ring of these conductors are loosely held and even a low EMF will cause the flow of free electrons.

Many metals are good conductors, especially gold, silver, copper, and aluminum. But not all conductors have the same amount of resistance to the flow of free electrons.



Conductor

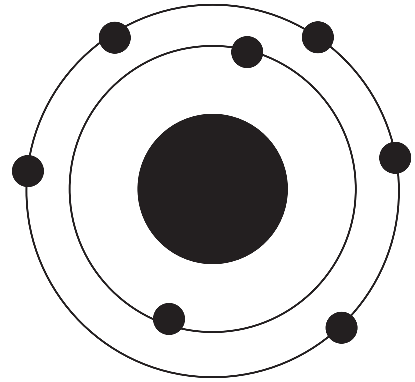
Insulators

Materials with 5-8 electrons in their outer ring have those electrons bound tightly. These materials are insulators (Poor conductors).

The electrons in the outer rings resist movement, the atoms don't give up the electrons easily or accept free electrons easily.

This effectively stops the flow of free electrons and thus any electrical current.

Materials such as rubber, glass, and certain plastics are examples of good insulators.



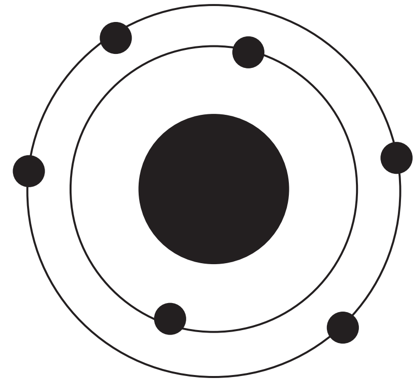
Insulator

Semi-Conductors

Materials with exactly 4 electrons in the atoms outer ring are neither conductors nor insulators.

The 4 electrons in the outer ring cause special electrical properties which give them the name "Semi-Conductor".

Materials such as Germanium and Silicone are two widely used semi-conductors.



Semiconductor

Electromotive Force

Friction, light, heat, pressure, chemical reaction or magnetic action are all ways that electrons are freed. The free electrons will move away from the "Electron Moving Force" (EMF). A stream of free electrons form an electrical current.

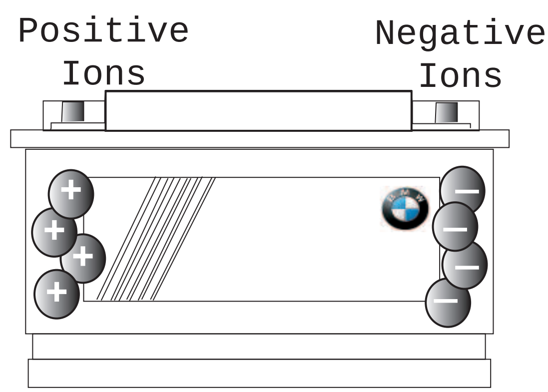
EMF	Method	Automotive Uses
Friction	Static, Walking Across Carpet	Electrostatic Field, Capacitor
Light	Photoelectric Cell, Light Controls	Headlamp and Mirror Sensors
Pressure	Piezoelectric, Speakers, Microphone	Knock and Side Impact Sensors
Chemical	Dry/Wet Cell Batteries	Primary Automotive EMF, Battery
Magnetic	Electromagnetic Induction, Coils	Secondary Automotive EMF, Generator

The battery and the generator are the primary and secondary means by which free electrons are generated in automobiles.

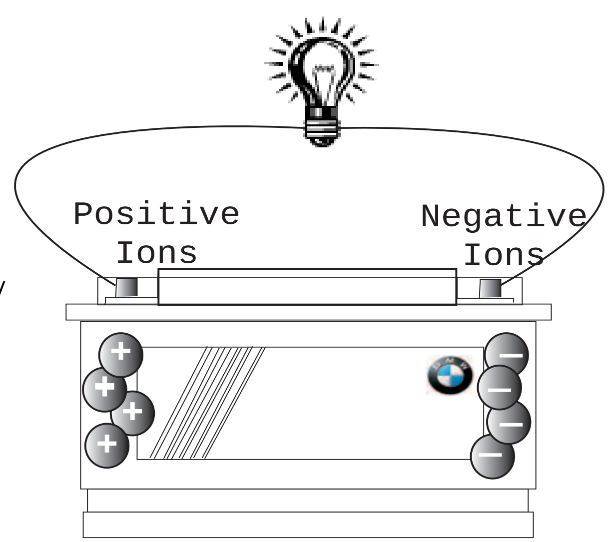
The chemical reaction taking place in the battery creates an Electromotive Force (EMF) that provides us with the positive ions and negative ions.

The generator through magnetic induction is our other source of free electrons. (Positive and negative ions)

The positive ions collect at the positive battery terminal and the negative ions collect at the negative battery terminal.



The positive and negative ions provide no energy unless a path between them is established. This path is normally in the form of a load (e.g. bulb, electric motor or other electrical consumer) placed across the positive and negative terminals of the battery either directly or through wires.



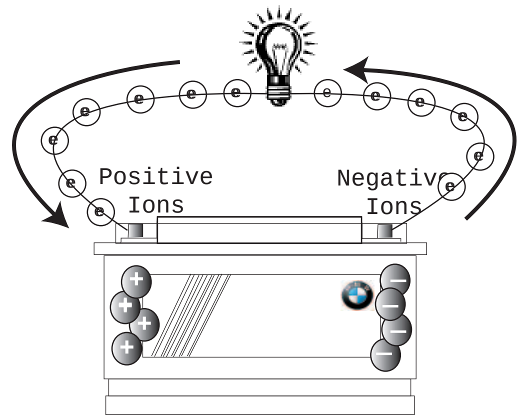
Theory of Electron Flow

Free electrons are pushed out of the battery negative terminal through a conductor to the positive terminal. When a path is established electrons have a route from the negative terminal to the positive terminal of the battery.

That route may take the electrons through wires, motors, light bulbs or other electrical consumers.

The mission of the electrons is always to return to the source of their energy which is the battery.

The Theory of Electron Flow represents the actual path of the electrons in an electrical circuit, from negative to positive.



Theory of Electron Flow

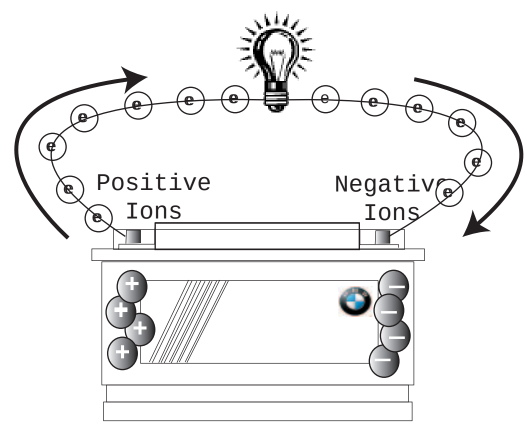
Conventional Theory of Electron Flow

Before Science gave a glimpse of the electron, it was generally believed that electricity (electrons) flowed from the positive charge to the negative charge.

Most electrical symbols, wiring diagrams, and teaching is based on the “Conventional Theory of Electron Flow” which states that electrons flow from positive to negative.

From this point on all references to current flow will be defined by the Conventional Theory of Electron Flow.

Conventional Theory of Electron Flow. is sometimes referred to as the Automotive Theory of Electron Flow.



Conventional Theory of Electron Flow

Notes:

Voltage

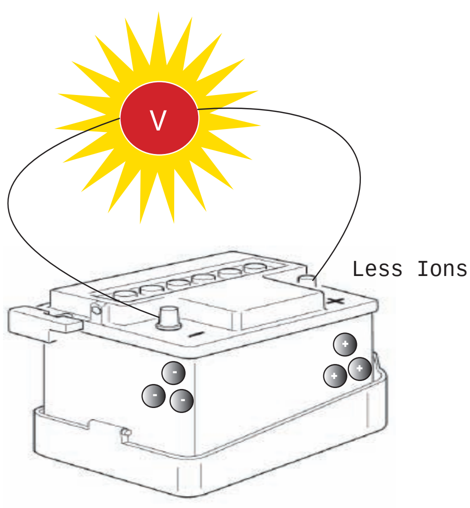
The potential of the electrons to flow is measured in **Volts**.

Think of voltage as pressure, the driving force (pressure) pushing the electrons from positive to negative.

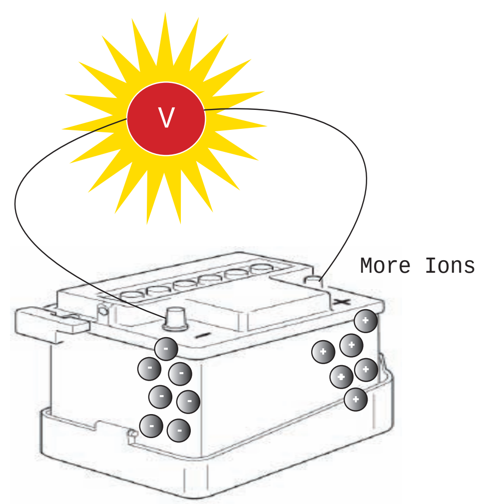
"One volt is the potential difference required to push one Amp of current through one Ohm of resistance."

Voltage is present between two points when a positive charge exists at one point and a negative charge at the other point.

The amount of voltage available is dependent on the number of ions at each terminal of the battery.



Less Voltage



More Voltage

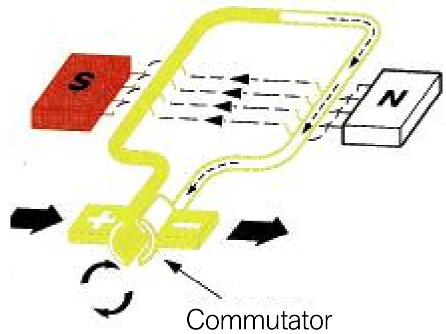
Note: Maintaining proper voltage is important. As voltage drops, so does the capacity for current flow.

Generating Voltage

Generator

In a generator, the conductor moves through a stationary magnetic field inducing voltage at the commutator, which connects to the circuit through brushes.

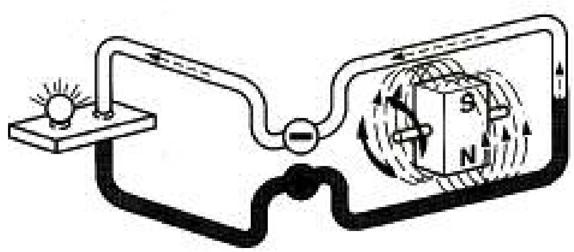
The voltage induced is direct current.



Alternator

In an alternator the magnetic field moves (rotates) through the stationary conductor producing voltage in the circuit.

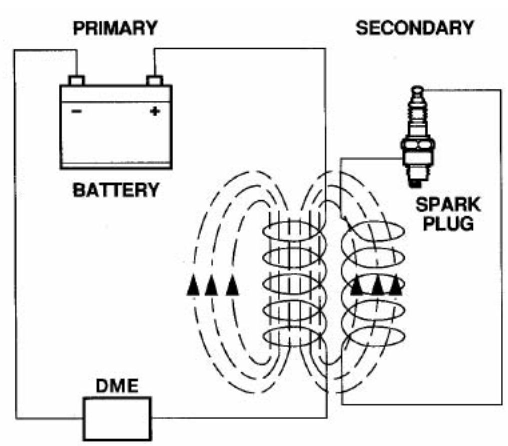
The voltage induced is alternating current.



Ignition Coil

Voltage can be induced by the building or collapsing of a magnetic field across a stationary conductor.

B+ power is supplied by the battery and a magnetic field is set up around the coiled conductor. The DME grounds or pulls low the current from the conductor and the loss of current causes the magnetic field to collapse inducing voltage in the secondary conductor.



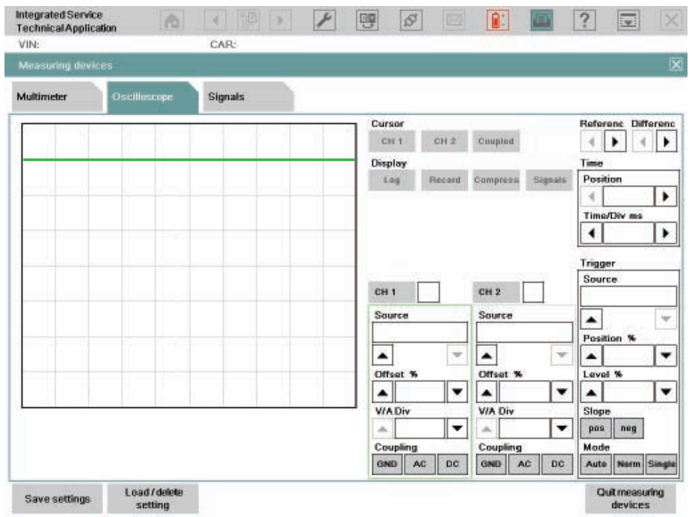
Electrical Units

Voltage

DC Voltage

A flow of current that moves continuously in one direction from a point of high potential to a point of low potential is referred to as DC (Direct Current).

Most automotive circuits operate on DC voltage as supplied by the battery(s).

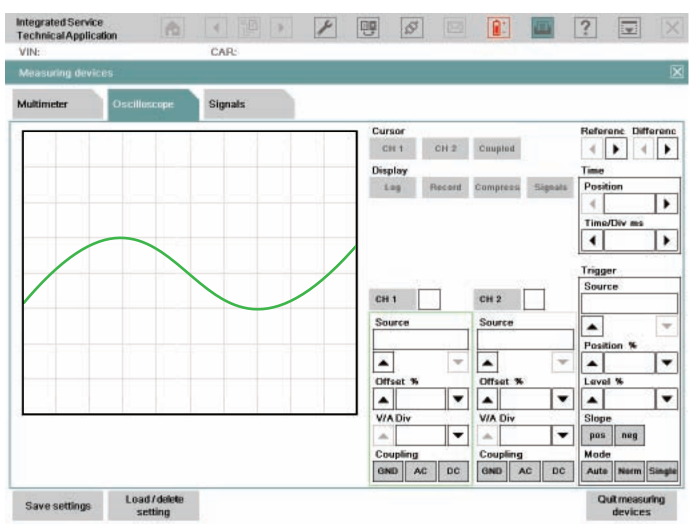


AC Voltage

Current which reverses its direction at regular intervals is called AC (Alternating Current).

This regular and continuous reversal of current flow (cycle) occurs many times per second.

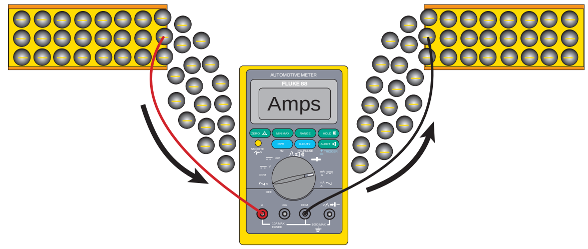
AC voltage as produced by an automotive alternator must be changed to direct current so that the battery can be charged.



Ampere
The unit of measure for current flow is the "Ampere", commonly referred to as "Amps".

Amps is the counting of electrons flowing on a conductor past a given point. One amp of current flow is equal to 6.23 billion billion (6.23×10^{18}) electrons moving past a point in one second.

Amps allow you to measure the volume of electrical energy "amperes" flowing through a wire or electrical consumer.

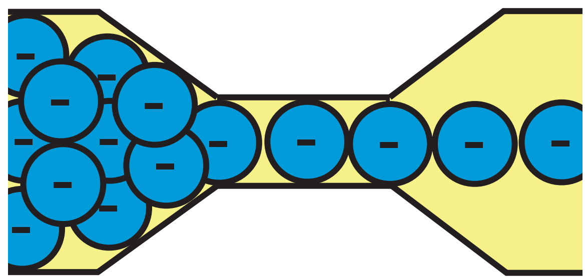


Ohms
The **"Resistance"** of a circuit opposes current flow. The unit of measure for resistance is the **"Ohm"**.

One ohm is defined as the amount of resistance that will allow one amp to flow when being pushed by one volt of pressure.

Resistance slows the flow of current (reduces the number of electrons flowing).

Resistance changes electrical energy into another form of energy (e.g. heat, light or motion).

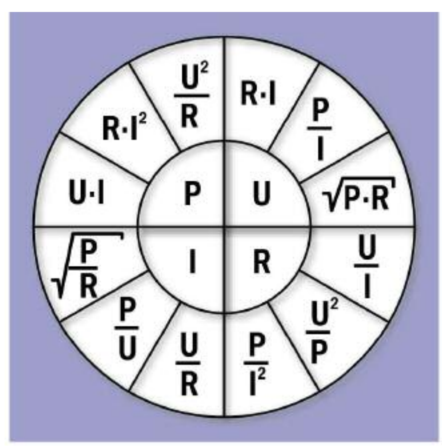


Resistance reduces the number of electrons flowing

Watt
Measure of electrical power.

Generally speaking, power is the ability to perform work within a defined period of time.

The basic unit of electrical power is the Watt (W) or Volt-ampere (VA). The latter is derived from the calculation with voltage and current.



Electrical Units of Measure			
Unit of Measure	Symbol	Basic Unit	Units
Volt	V, U,or E	Volt	V = Volt = 1 volt mV = millivolt = .001 volt KV = Kilovolt = 1,000 volts
Ampere	Amp, A, or I	Amp	A = amp = 1 amp mA = milliamp = .001 A KA = Kiloamp = 1,000 A
Ohm	Ω	Ohm	1W = 1 ohm mW = milliohm = .001 ohm K = kilo-ohm = 1,000 ohms M = Megaohm= 1,000,000 ohms
Watt	W	Watt	1W = 1 Watt mW = milliwatt = .001 Watt K = kilo-watt = 1,000 Watt M = Megawatt= 1,000,000 Watt

Circuits

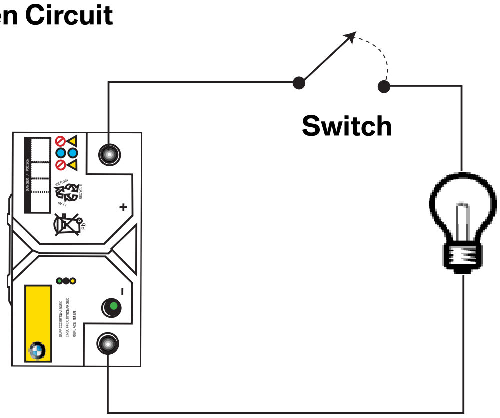
Electricity must have a complete or closed loop circuit to flow. A "Circuit" is defined as an unbroken, uninterrupted path which begins and ends at the same point. In the automobile that point is the battery. The electron flow must be from the battery through the wiring and consumers back to the battery. That flow represents a complete circuit.

A typical circuit will contain:

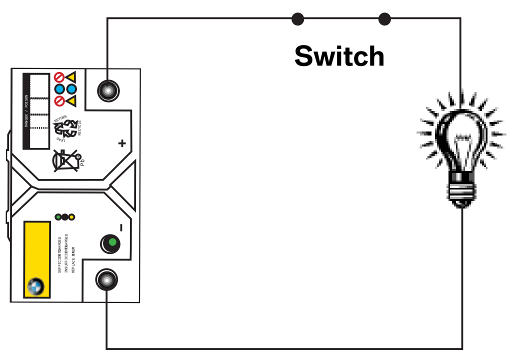
1. A battery and/or generator system (EMF or source of the electrons)
2. Conductors (wiring to deliver the electrons to the consumers)
3. Consumers (the load being placed on the system)

Any break or interruption in this circuit will cause the circuit to cease operation.

Open Circuit



Complete/Closed Circuit



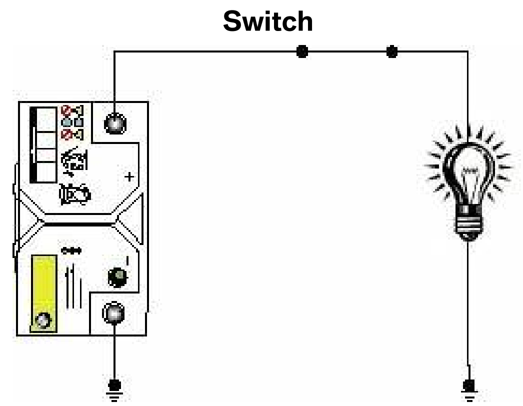
There are three basic types of circuits:

- Series
- Parallel
- Series/Parallel

Series Circuit

A Series circuit provides one path for the current flow. That path is from the source of the current (the battery) through a conductor, consumer and back to the source.

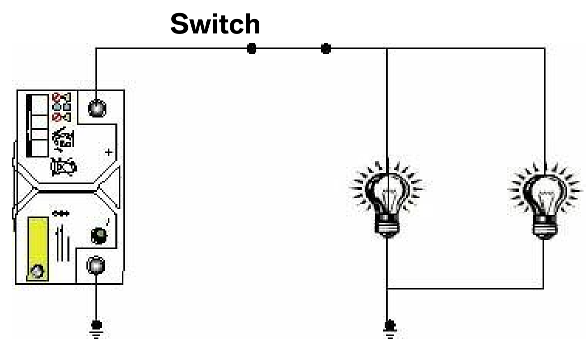
A Series circuit provides constant current flow (amps) through the entire circuit. Amps measured in any two places in the circuit will be equal.



Parallel Circuit

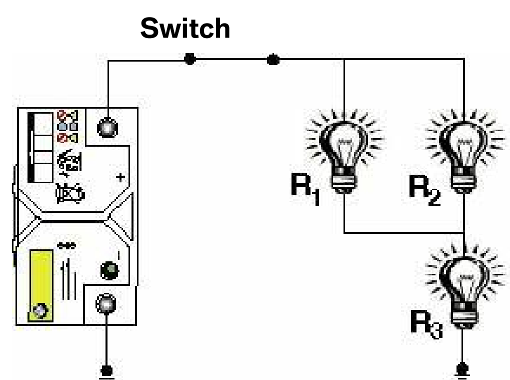
A Parallel circuit provides multiple current paths. In a Parallel circuit, all of the component's positive terminals are connected to one point and all of the component's negative terminals are connected to a different common point. Source voltage is the same at all loads.

The current flow in a parallel circuit will be equal to the sum of the current flowing through each branch of the circuit.



Series-Parallel Circuit

A Series-Parallel circuit contains portions of the current path that are in series with each other and other portions of the path that are parallel with each other. A headlight circuit would typically be this type of Series/Parallel circuit. The headlight switch is in series with the headlights, and the headlights are in parallel branches with each other.



Ohm's Law

The key to intelligent troubleshooting of electrical circuits is a thorough understanding of Ohm's Law. Ohm's Law states that the current flowing in a circuit varies directly with the voltage and inversely with the resistance.

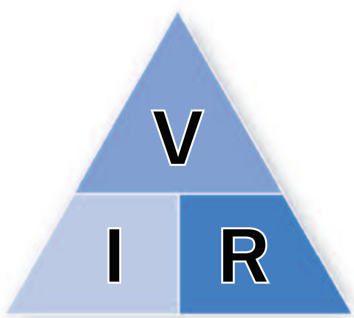
The pressure of one volt applied to one Ohm of resistance will cause one amp of current to flow. If the voltage increases, current will increase. If resistance increases, current will decrease.

Knowing any two of the three factors (volts, resistance or current) enables the third factor to be calculated using Ohm's Law.

The mathematical expression is: **Volts = Resistance X Current**

This formula is expressed in the Ohm's Law Triangle.

To find a missing factor, insert the known factors in the appropriate position and perform the math. A horizontal line between two factors means to divide, a vertical line means multiply.



Ohm's Law Triangle

V (also U or E) = Volts

I (also A) = Current in Amps

R = Resistance in Ω

Note: "I" refers to current intensity.

Understanding of Ohm's Law is essential in the diagnosis of electrical problems. A practical understanding of how the three factors affect each other is equally useful.

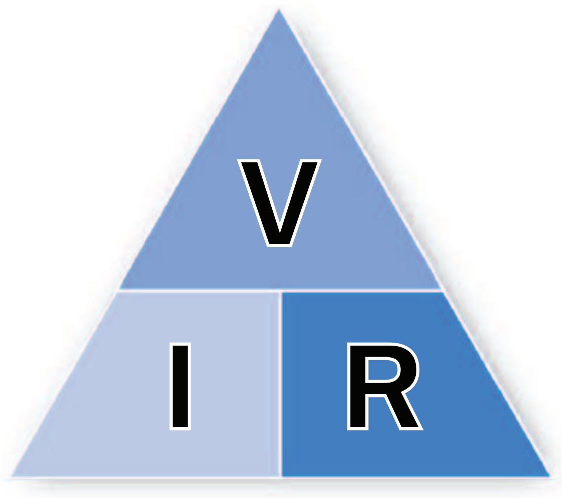
- Source voltage is not affected by current or resistance. It can only have three states.
  Too low - Current flow will be low.
  Too high - Current flow will also be too high.
  Correct voltage - Current flow will be dependent on the resistance.
- Current Flow will be directly affected by either voltage or resistance.

  High voltage or low resistance will cause an increase in current flow.
  Low voltage or high resistance will cause a decrease in current flow.
- Resistance is not affected by either voltage or current. Resistance like source voltage can have only three states.

  Too low - current will be too high if the voltage is ok.
  Too high - current flow will be low if the voltage is ok.
  Correct resistance - current flow will be high or low, dependent on voltage.

Ohm's Law - Series Circuits

Applying Ohm's Law in a series circuit requires simple math. The current has only one path. Circuit resistance total is arrived at by adding the individual resistances. Amperage is calculated by dividing source voltage by the total resistance.

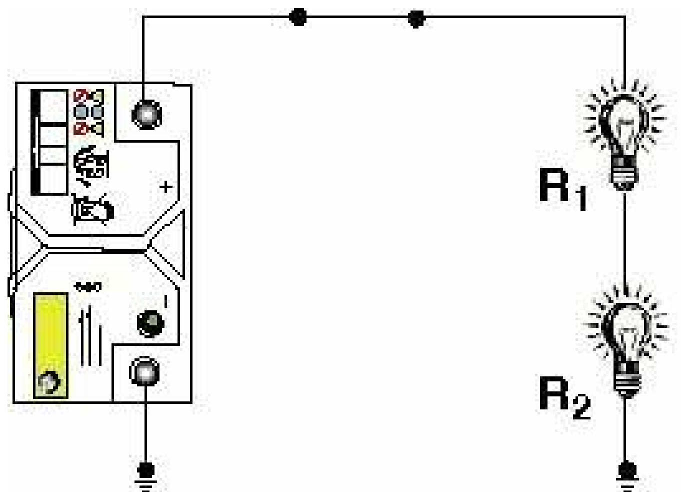


Key Features - Series Circuit:

- Current through each load is the same.
- Total resistance equals the sum of the individual resistances.
- Voltage drop across each load will be different if the resistance is different.
- Total voltage drop equals source voltage.

Example:

Series Circuit



$$R_1 + R_2 = R_t$$

$$V / R_t = A$$

If: $R_1 = 2\Omega$
$R_2 = 4\Omega$
$V = 12.0$ volts
$A = ?$

To calculate total resistance.

$R_t = R_1 + R_2$
$R_t = 2 + 4$
$R_t = 6\Omega$

Now that the total resistance is known, we can calculate for the amperage.

$A = V / R_t$
$A = 12 / 6$
$A = 2$ *Amps (I)*

The total amperage can be used to calculate the expected voltage drop at each bulb?

$A \times R_1$ = *voltage across bulb 1* — $A \times R_2$ = *voltage across bulb 2*
$2 \times 2 = 4$ *volts* — $2 \times 4 = 8$ *volts*

If the two voltage drops are added, the result should be source voltage.

Voltage drop across bulb 1 + voltage drop across bulb 2 = source voltage
$4\ v + 8\ v = 12\ v$

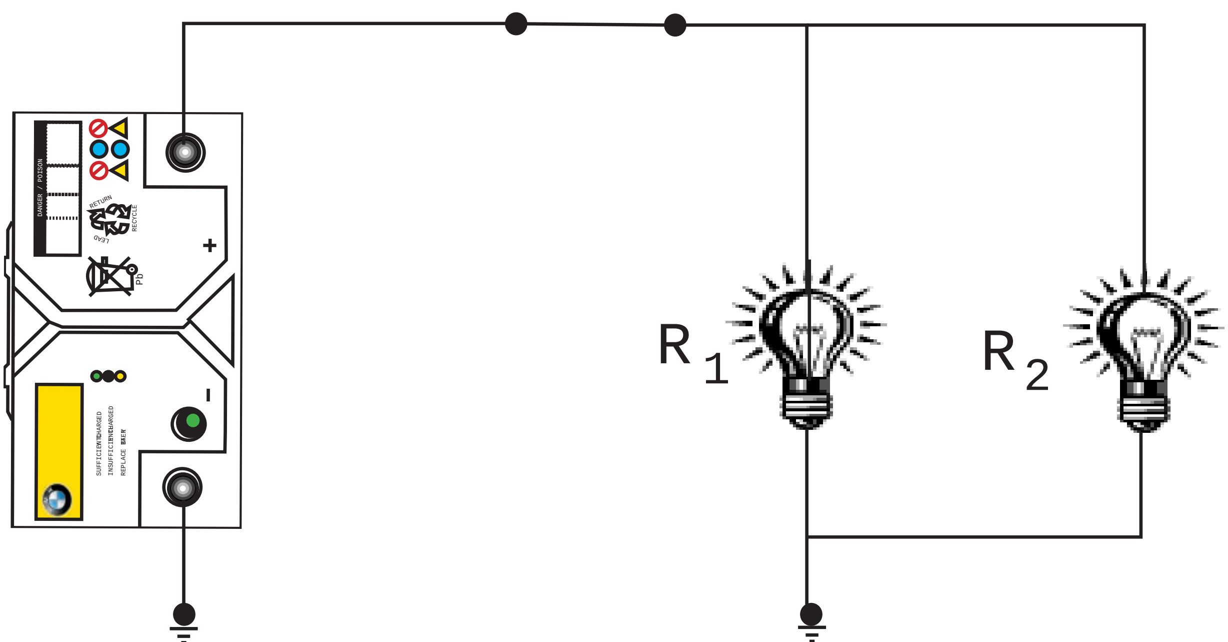
Ohm’s Law Parallel Circuit - 2 Branches

A Working in a Parallel circuit requires a little more math. Each branch of the circuit has it’s own path to the voltage source. Before amps are calculated total circuit resistance must be found.

Key Features - Parallel Circuit:

- Current flow through each branch can be different if the resistances are different.
- Total Resistance of the circuit is less than the resistance of the lowest branch.
- Voltage drop across each branch circuit is the same.
- Total current is the sum of the branches.

Parallel Circuit



Example 1:

If: $R_1 = 3\Omega$

$R_2 = 6\Omega$

Voltage = 12.0 volts

The current for both branch R_1 and R_2 can be calculated using Ohm's Law.

V / R_1 = *branch current* V / R_2 = *branch current*

12 / 3 = 4 amps *12 / 6 = 2 amps*

We can add the current flowing through each branch to determine the total amperage.

Amperage of branch 1 + Amperage of branch 2 = Total circuit current

4 a + 2 a = 6 amps

We can also calculate for the total resistance of the circuit.

$R_t = (R_1 \times R_2) / (R_1 + R_2)$

$R_t = (3 \times 6) / (3 + 6)$

$R_t = 2\Omega$

Example 2:

If: $R_1 = 6\Omega$

$R_2 = 6\Omega$

To calculate the total resistance in an parallel circuit with resistances that are the same we could use the formula:

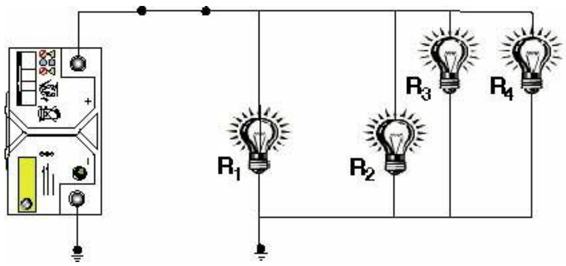
$R_t = R_{(either)} / 2$

$R_t = 6 / 2$

$R_t = 3\Omega$

Ohm's Law Parallel Circuit - More than 2 Branches

Calculating circuit resistance in a Parallel circuit with more than 2 branches is performed by one of two methods. All the key features for a Parallel circuit still apply.



Parallel Circuit

Key Features Parallel Circuit

- Voltage drop across each branch circuit is the same.
- Current flow through each branch can be different if the resistance is different.
- Total resistance of the circuit is less than the lowest resistance.
- Total circuit current is the sum of the branches.

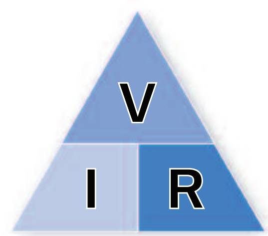
Example: 1

If: $R_1 = 3\Omega$

$R_2 = 3\Omega$

$R_3 = 6\Omega$

$R_4 = 4\Omega$



To calculate the total resistance we can use the formula:

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}}$$

$$R_t = \frac{1}{\frac{1}{3} + \frac{1}{3} + \frac{1}{6} + \frac{1}{4}}$$

$$R_t = \frac{1}{\frac{4}{12} + \frac{4}{12} + \frac{2}{} + \frac{3}{}} \quad or \quad R_t = \frac{1}{.33 + .33 + .167 + .25}$$

12 12

$$R_t = \frac{1}{\frac{13}{12}} = \frac{12}{13} \quad or \quad R_t = \frac{1}{1.08}$$

$$R_t = .92\,\Omega$$

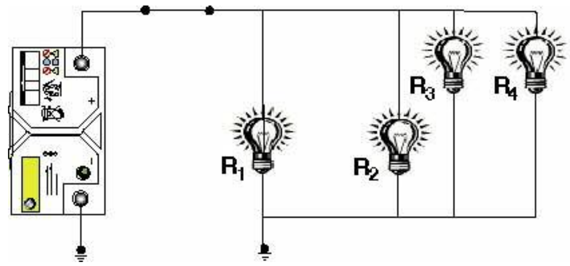
Example: 2

If: $R_1 = 3\Omega$

$R_2 = 3\Omega$

$R_3 = 6\Omega$

$R_4 = 4\Omega$



To calculate the total resistance we can use the formula $R_{br} = (R_1 \times R_2) / (R_1 + R_2)$ to calculate the resistance of two branches at a time.

$R_{br1} = (R_1 \times R_2) / (R_1 + R_2)$
$R_{br1} = (3 \times 3) / (3 + 3)$
$R_{br1} = 9 / 6$
$R_{br1} = 1.5\Omega$

$R_{br2} = (R_{br1} \times R_3) / (R_{br1} + R_3)$
$R_{br2} = (1.5 \times 6) / (1.5 + 6)$
$R_{br2} = 9 / 7.5$
$R_{br2} = 1.2\Omega$

$R_t = (R_{br2} \times R_4) / (R_{br2} + R_4)$
$R_t = (1.2 \times 4) / (1.2 + 4)$
$R_t = 4.8 / 5.2$
$R_t = .92\Omega$

Either formula you choose to utilize to calculate total resistance in a parallel circuit that has two or more branched will render the correct answer.

Please note that the following rules are still applicable all for this parallel circuits:

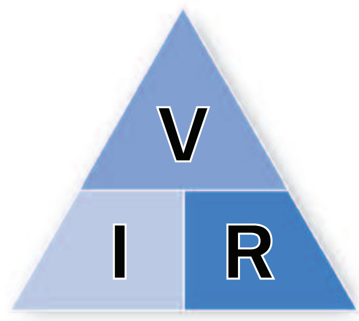
- Current flow through each branch can be different if the resistances are different.
- Total Resistance of the circuit is less than the resistance of the lowest branch.
- Voltage drop across each branch circuit is the same.
- Total current is the sum of the branches.

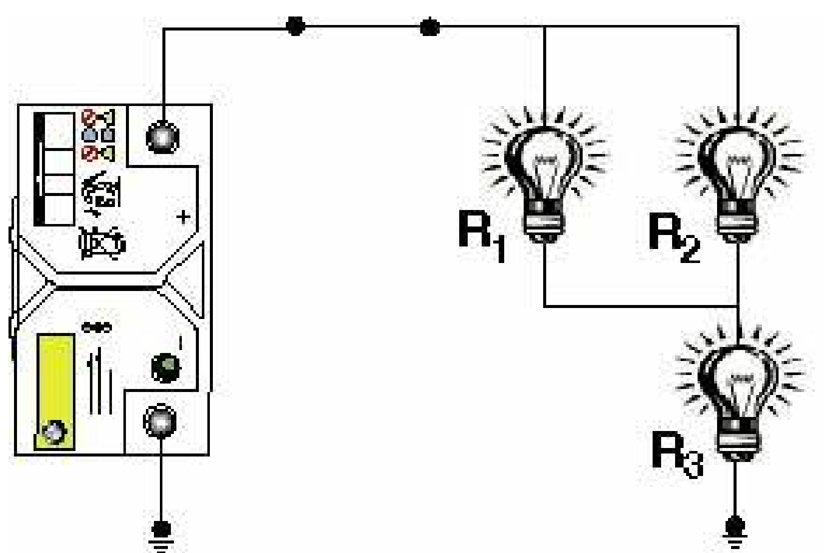
Ohm's Law in Series-Parallel Circuit

When calculating resistance in a series-parallel circuit, always calculate the equivalent resistance in the parallel portion of the circuit. Then add this resistance (equivalent resistance) to the resistance of the series portion of the circuit.

Key Features - Series-Parallel Circuit:

- Current in the series portion of the circuit is the same at any point of that portion.
- Total circuit resistance is the sum of the parallel branch equivalent resistance and the series portion resistance.
- Voltage applied to the parallel branch is source voltage minus any voltage drop across loads wired in series to the parallel branch in front of it in the circuit.
- The series portion of the circuit directly affects the parallel branches of that circuit.





Series Parallel Circuit

Example: 1

If: $R_1 = 4\Omega$

$R_2 = 6\Omega$

$R_3 = 2\Omega$

Calculate the equivalent resistance value of R1 and R2.

Remember the resistance of a parallel circuit is lower than the lowest resistance in that circuit. The resistance of this portion of the circuit must be lower than 4Ω, the lowest resistance.

$$R_{parallel\ branch} = (R_1 \times R_2) / (R_1 + R_2)$$
$$R_{parallel\ branch} = (4 \times 6) / (4 + 6)$$
$$R_{parallel\ branch} = 2.4\Omega$$

Now follow the rules of a Series circuit.

The total circuit resistance is equal to the sum of the individual resistances.

$$R_t = R_{parallel\ branch} + R_3$$
$$R_t = 2.4\Omega + 2\Omega$$
$$R_t = 4.4\Omega$$

Alternate Formula for equivalent resistance:

Find the current draw of each parallel branch, add together to get the total current draw of the parallel portion, then using ohms law find the resistance of the parallel branch.

Electrical Power

From a technical point of view, the colloquial expression "current consumption" is not correct as the current that flows into a device also flows out of it again. As a matter of fact the electrons in standard household current only move a short distance back and forth in the conductor without an appreciable number of electrons flowing out of the line into the device. What actually "flows" is electrical energy. This energy is also not consumed but rather it is converted, e.g. into mechanical energy (motor), thermal energy (hair dryer) and chemical energy (charging batteries for mobile phones). The work performed (the product of voltage, current and time) is determined with an electricity meter. For this reason, the "current consumption" is counted in kilowatt hours and not in the unit of current ampere.

Generally speaking, power is the ability to perform work within a defined period of time.

Electrical power is a value that can be found in the most diverse variety of definitions in electronics and electrical engineering. The common factors of all power (for direct voltage) are the unit of measure and the formula symbol.

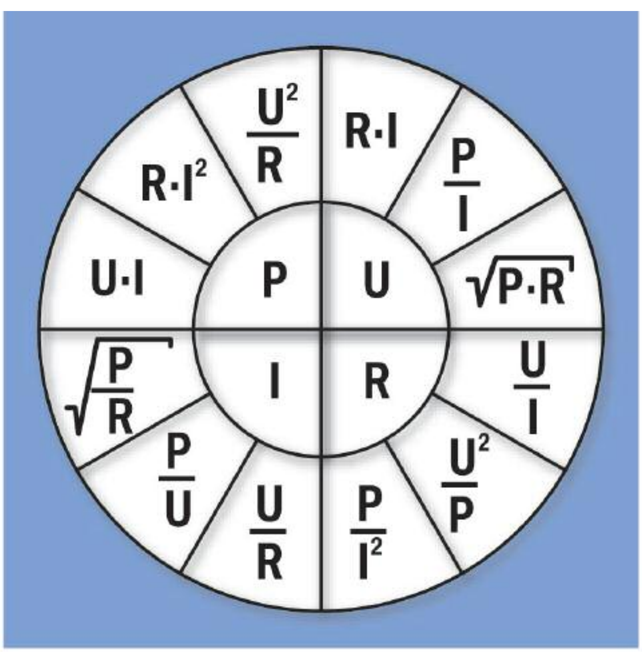
Formula Symbol

The formula symbol for power is upper case P.

Unit of Measure

The basic unit of electrical power is the Watt (W) or Volt-ampere (VA). The latter is derived from the calculation with voltage and current. The unit of measure VA can be found often on transformers and electric motors.

The mathematical relationship between electrical power P, electrical voltage U, electrical current and electrical resistance is represented in the following diagram.



P = U * I

P = V * A

U = Voltage

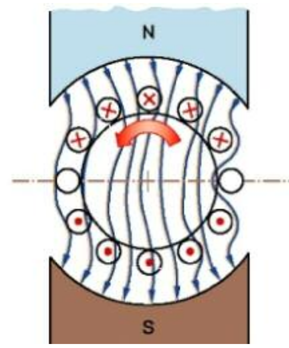
I = Amperage

P = Power

R = Resistance

A DC motor has a rated power of 10 kW. The rated current as stated on the type plate is 20 A. What is the motor's nominal voltage?

$$U = \frac{P}{I} = \frac{10000\ W}{20\ A} = 500\ V$$



What is the power loss on a cable with a resistance of 1 mΩ carrying a current of 420 A?

$$P = I^2 * R = (420\ A)^2 * 1 m\Omega = 176.4\ W$$

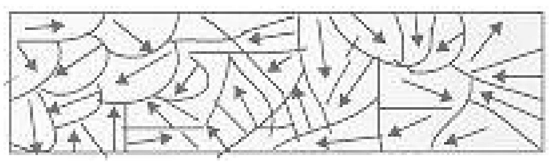
Worksheet Calculations

Magnetic Theory

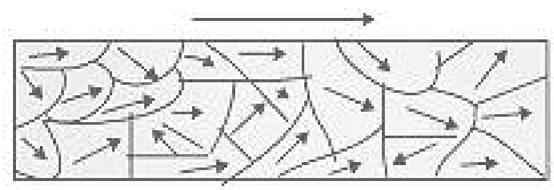
The usefulness of electricity is greatly expanded through magnetism. Magnetism enables the existence of electric motors, generators, coils, relays, solenoids, transformers, etc. Magnetism, like electricity, can't be seen, weighed on a scale or measured with a ruler. How it works and is put it to use can be understood.

Two theories exist to explain how magnets work. The first theory states that a large quantity of small magnetized particles exist in a magnet. If the item is not magnetized the particles are arranged in a random order. When the item becomes magnetized the particles align with each other.

The second theory states that when the electrons of atoms are arranged in a certain order, the circles of force of each atom combine creating the magnetism.



Non Magnetized Iron Bar



Magnetic Iron Bar

Fundamentals of Magnetism

- A magnet sets up a field of force.
- Magnetic lines of force form closed loops that flow from North to South.
- The space through which magnetic lines of force flow is called the magnetic field.
- The magnetic field is strongest closer to the magnet and becomes weaker as it gets further away.
- Magnetic lines of force never cross each other.
- There is no known insulator against magnetism.
- Magnetic lines pass more easily through iron and steel than air.
- Opposing forces will occur at opposite ends of the magnet (Polarity). One end is the North Pole (+), the opposite end is the South Pole (-).
- Like poles repel each other, unlike poles attract each other.
- Some materials (wood, ceramics, and some metals) cannot be magnetized.

There are two common types of magnets:

- **Permanent Magnets** - made from materials such as hardened steel that become magnetic when subjected to an outside magnetizing force and remain magnetic even after the outside force has been removed.
- **Temporary Magnets** - made from materials such as soft iron that remain magnetic only as long as an outside magnetic force is present.

The lines of force of all magnets, either permanent or temporary flow from the North Pole of the magnet to the South Pole. The magnetic lines of force or “flux” are stronger closer to the magnet and get weaker as the distance from the magnet increases. (Fig. 19/1)

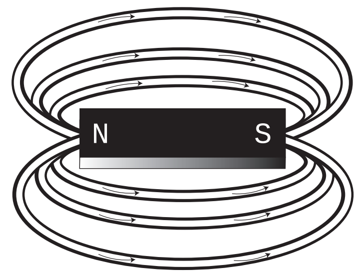


Fig.19/1

Polarity refers to the opposing forces occurring at opposite ends of the magnet. All magnets have a North Pole and a South Pole. Like poles will repel each other and unlike poles will attract. (Fig.19/2)

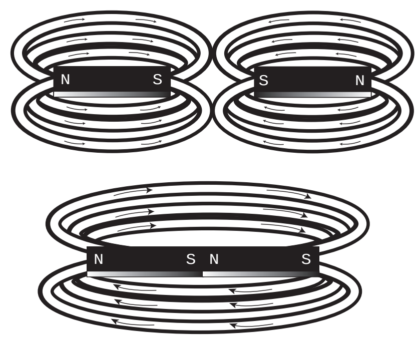


Fig.19/2

Most temporary magnetic fields are produced by electricity flow. Whenever current flows through a conductor magnetic lines of force develop around the conductor.

These lines of force form a circular pattern. The lines can be visualized as a magnetic cylinder extending the entire length of the conductor. (Fig.19/3)

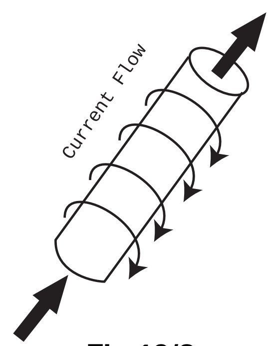


Fig.19/3

The lines of force have direction and change dependent on direction of current flow.

The density of the lines of force are dependent on current flow through the conductor. The greater the current flow, the stronger the magnetic field that will be around the conductor.

Passing a current flow through a conductor will not generate a magnetic field strong enough to perform any work.

If the conductor is coiled, the lines of force combine and become more dense forming a stronger field (Fig.20/1).

The greater the number of turns of the conductor or the stronger the current flowing through the conductor the stronger the magnetic field.

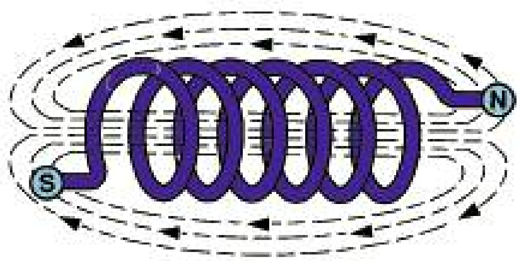


Fig.20/1

Inserting an iron core in the coiled conductor increases the magnetic field even more as iron makes a better path for the magnetic lines than air (Fig.20/2).

This conductor wound around an iron bar is an “Electromagnet”. A coil with an air core is a “Solenoid”.

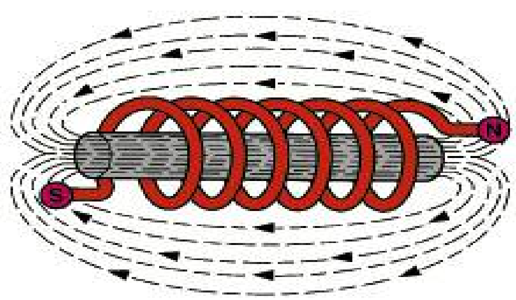


Fig.20/2

Electromagnetic Induction

Producing a magnetic field by flowing current through a conductor is a process that can be reversed. A magnetic field can be set up that will cause current to flow in a conductor. This is called inducing or generating electricity by magnetism.

To induce voltage in a conductor it is necessary to have relative motion between the conductor and the magnetic field. This motion can be in any one of three forms:

- The conductor moves or rotates in a stationary magnetic field as in a DC Generator.
- The magnetic field rotates in a stationary conductor producing voltage in the circuit as in an AC Generator or Alternator.
- The building or collapsing of a magnetic field across a stationary conductor, as in an Ignition Coil.

Coil

A basic coil is represented by a length of wire wound about a solid body. This body, however, is not absolutely necessary. Its main purpose is to stabilize the thin wire.

By winding a current conductor to form a coil, the lines of magnetic field will be bundled on the inside of the coil where they run parallel and with the same density. This is known as a homogeneous magnetic field. A north pole is created at the outlet of the field lines and a south pole at the inlet.

The most important physical property of a coil is its inductance.

The inductance of a coil is the ability to convert electrical energy into magnetic energy in its own windings.

In addition to inductance, however, standard coils exhibit other (mostly undesirable) properties such as electrical resistance or capacitance.

The strength of the magnetic field of a coil depends on:

- The number of windings N,
- current intensity I and
- the structure of the coil

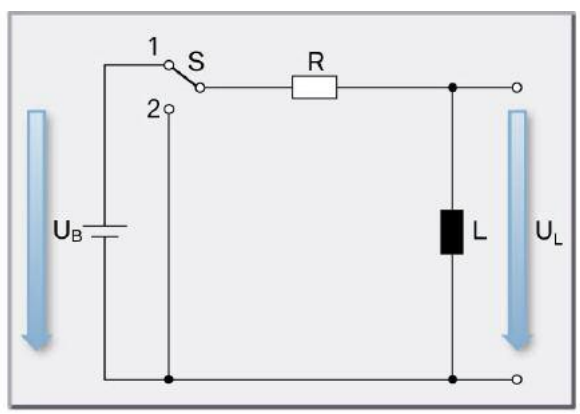
The magnetic field can be boosted by a factor of 1000 by placing an iron core in the coil. The iron core is not part of the current circuit. Such a coil with an iron core is known as an "electromagnet". The soft magnetic iron core remains magnetic only for as long as current I flows through the coil.

A switch S connects a coil L via resistor R to a direct voltage source.

Almost the entire voltage UB is applied at the coil at the moment the switch is switched on.

At this moment, the coil acts as an interruption, i.e. it therefore behaves in the reverse way compared to a capacitor. With time, the current flowing through the coil increases and the voltage applied at the coil decreases.

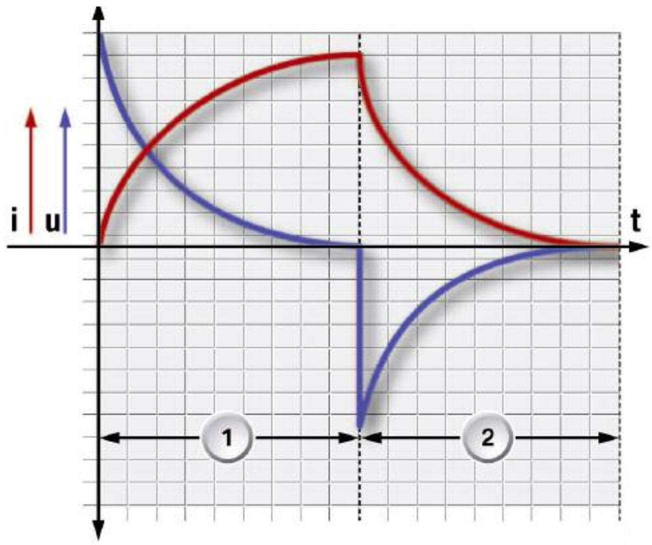
Coil in a direct current circuit



Index	Explanation
S	Switch
1	Voltage on
2	Voltage off
R	resistor
L	Coil

The magnetic field produced in the coil collapses when the voltage UB is switched off thus inducing a voltage. This voltage UL enables a current to flow through resistor R until the magnetic field is completely converted to electrical energy and is converted to heat in resistor R.

Voltage and current progression in a coil



Index	Explanation
1	Build-up of magnetic field
2	Break-down of magnetic field
i	Current
u	Voltage

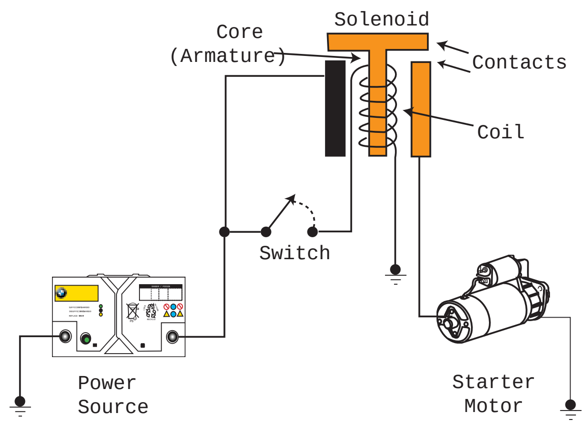
If there is no closed-current circuit after switching off the voltage UB, the induced voltage will greatly increase and a spark will jump across the open switch (arcing).

Solenoids

A Solenoid, like a relay, uses current flow and electromagnetism to produce mechanical movement. Solenoids consist of a coil winding around a spring loaded metallic plunger.

When current flows through the winding, the magnetic field attracts the movable plunger, pulling it against spring pressure into the center of the coil. When current flow stops, the magnetic field collapses and the plunger is moved out of the coil by spring pressure.

Solenoids are commonly used in starter motors, injectors and purge valves.



Starter Solenoid Circuit

Switches

A Switch is a mechanical device used to start, stop or redirect current flow. A switch can be installed on the positive side of the circuit or the negative side of the circuit. A switch can be used to control a load device directly or used to operate a relay which in turn can operate a higher current device. (e.g. Headlight switch, Horn button and Window switch.)

Pushbuttons and microswitches belong to the group of contact sensors. They generate a signal when they are subjected to a force (press, release). Switches and pushbuttons are often used to register certain statuses, e.g. whether a trunk lid is open or closed.

Pushbuttons output a signal only for as long as they are operated. They then return to their rest position.

When operated, switches lock in position and remain in the switching position, into which they were moved. They return to their initial position only when operated again and signal output is cancelled.

Mechanical switches are operated mechanically. They have one or several switch contacts or contact paths.

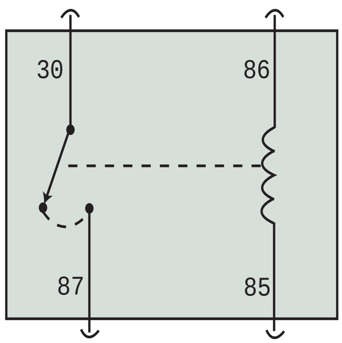
Microswitch

Relays

A Relay is a switch that uses electromagnetism to physically move the contacts.

A small of amount of current flow through a relay coil moves an armature and opens or closes a set of points.

The points control the flow of a larger amount of current through a separate circuit.



Think of the two sides of a relay independently.

- Control side: Which includes the B+(KL86) and B-(KL85) for the coil that creates the magnetic force. If this side of the relay fails open the work side points will remain in their at rest position.
- Work side: Which includes the B+ input power (KL30) and the Relay output (KL87). Failure of this side of the relay in the closed position (sticking points) will result in constant current flow.

BMW uses relays with various numbers of pins (3,4,5 pin) and pin configurations (normally open, normally closed and changeover type). **Do not substitute relays. Always replace with the same type** (e.g. DME Main Power Relay, Secondary Air Pump Relay and Rear Window Defroster Relay.).

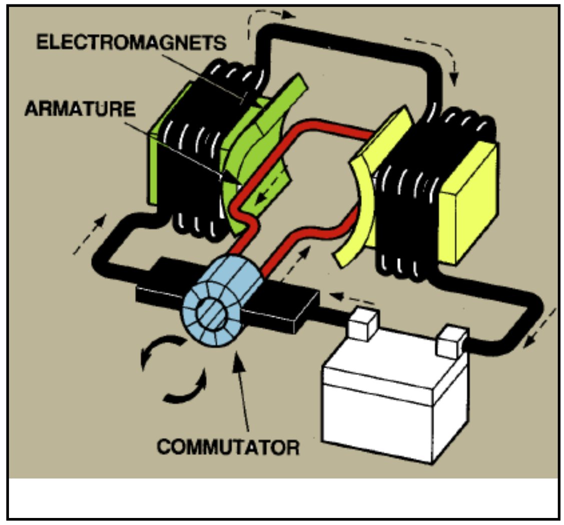
NAME	CIRCUIT
B+	Battery Positive
B-	Battery Negative
KL	Standardized Abbreviation for Clamp or Terminal Number
KLO	Ignition Switch Off
KLR	Voltage Ignition Switch in ACC, Run Start (Hot in Acc/ Run/ Start)
KL15	Voltage Ignition Switch in Run and Start (Hot (12v) in Run/ Start)
KL15U/15i	Voltage Ignition Switch in Run (Hot (12v) in Run)
KL15N	F0x, Voltage Ignition Switch in the run And Start. HOT (12V) in the Run/Start.
KL15WUP	Wake up
KL30	12v At All Times (Relay Work Power) (Hot (12v) All Times)
KL30g	12v with time disconnection
KL30B	F0x. 12v with time disconnection
KL30g_f	12V with fault disconnection
KL30F	F0x. 12V with fault disconnection
KL30H	Starter Signal
KL31	Ground
KL31E	Electronic ground
KL31L	Load ground
KL50	Voltage Ignition Switch in Start (Hot (12v) in Start)
KL58	Interior Lighting Dimmer Signal
KL61	Ground with Alternator Output, 12v with KL15
85	Relay Coil Ground (Signal) control side
86	Relay Coil B+ Control Side
87	Relay Output Work Side
87a	Relay Output Work Side At Rest

Electric Motors

There are a large number of electric motors installed in BMW vehicles, e.g. for the slide-tilt sunroof, power windows, seats, windshield wipers etc.

Two types of electric motors are of particular interest:

- Direct current motor
- Stepper motors



Direct Current Motor

A direct current motor converts electrical energy into rotational energy.

When current is passed through the armature of a DC motor, a torque is generated by magnetic reaction and the armature revolves.

The motor consists of a fixed part, the stator, and a rotating part, the rotor (armature). Most direct current motors (DC motors) are designed as internal rotor motors. The rotor is the inner part and the stator the outer part.

The stator consists of an electromagnet or a permanent magnet in smaller electric motors. The rotor is also known as the armature.

The principle of the electric motor is based on the fact that a force is exerted on a current carrying conductor in a magnetic field. The magnetic field of the current-carrying conductor and the magnetic field of the permanent magnet mutually influence each other. If the permanent magnet is fixed in position and the conductor is mounted such that it rotates, a force is exerted on the conductor causing it to rotate.

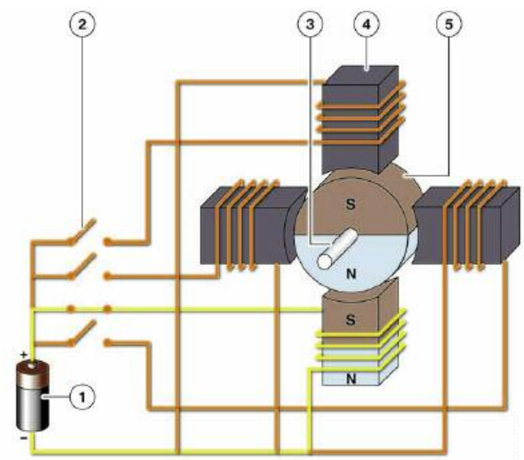
This force is dependent on:

- The strength of the electrical current in the conductor
- The strength of the magnetic field
- The effective length of the conductor (number of windings)

Stepper Motors

Stepper Motors behave differently than standard DC motors. Unlike DC motors which spin freely when power is applied, stepper motors do as their name suggests, they step or rotate incrementally a little bit at a time. While DC motors need higher speeds to produce higher torque, stepper motors provide their highest torque at their slowest speeds. Stepper motors also have holding torque, the ability to resist movement by outside forces.

Steppers are driven by the interaction (attraction and repulsion) of magnetic fields. The driving magnetic field rotates as strategically placed coils are switched on and off. This pushes and pulls at permanent magnets arranged around the rotor that drive the output shaft.



Functional principle of the stepper motor

Index	Explanation
1	Voltage source
2	Switch
3	Shaft of stepper motor
4	Electromagnet
5	Rotor (permanent magnet)

Stepper motors can be used successfully wherever controlled movements or positioning are required. They enable simple positioning control with a high degree of reliability and precision. They require a direct current supply, a control switch and control pulses (digital information) for their operation. The corresponding direct current is supplied to the motor via an electronic switch.

Depending on the type of stepper motor, the standard step angle is in the range from 2° to 15°.

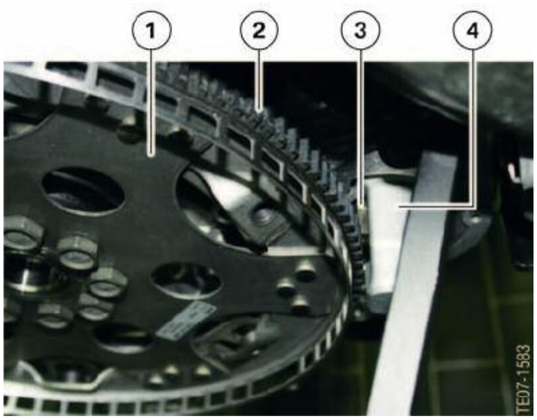
The position which the shaft of the stepper motor assumes corresponds to the relationship between the number of magnetic poles of the stator and the number of magnetic poles of the rotor. Since the rotor is equipped with permanent magnets, the poles are correspondingly defined. The stator always consists of two or more pole pairs with each pole enclosed by a coil with current passing through it to form a magnetic pole.

The magnetic field can be reversed by reversing the direction of current flow in the magnet windings. A rotating magnetic field which the permanent magnets of the rotor follow is created by successively reversing the direction of current flow in the stator coils in one direction. The rotary speed is determined by the speed at which the stator coils are switched over.

In BMW vehicles, stator motors are used, for example, in the integrated heating and air conditioning control system (IHKA) for controlling the air flaps (stratification, footwell, recirculating air and fresh air flaps).

Starter

The vehicle starter is a DC motor. It has the task of turning the crankshaft of the combustion engine at the minimum speed required to start the engine.



Index	Explanation
1	Flywheel
2	Ring Gear
3	Pinion
4	Starter

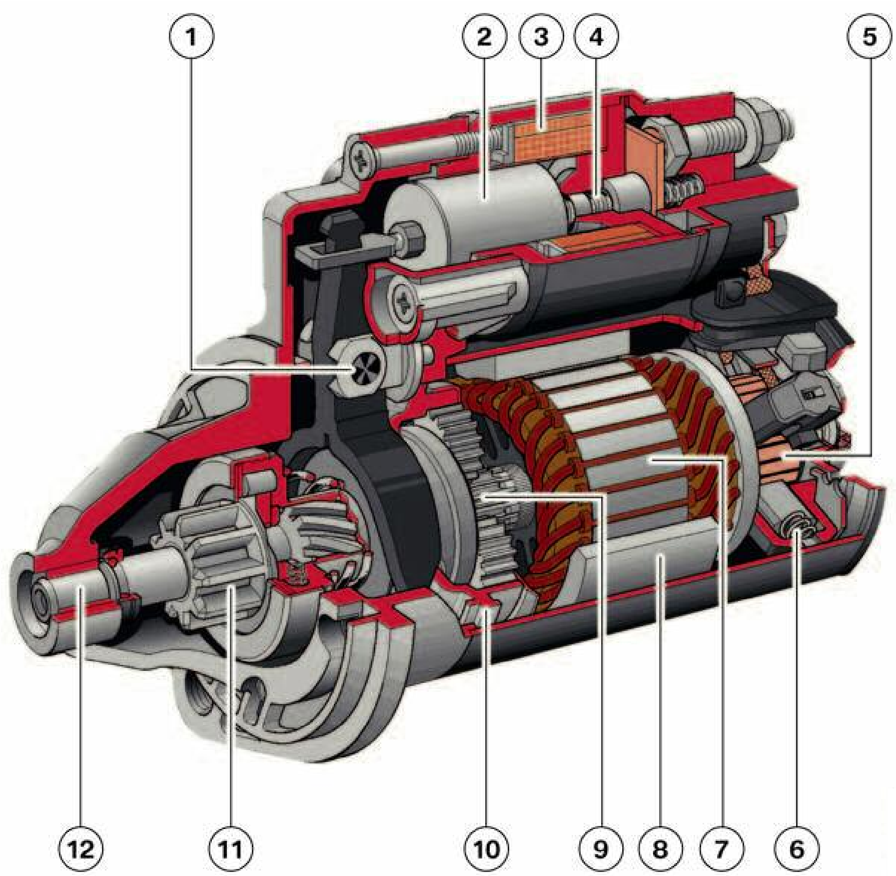
The principle of starting a combustion engine is based on a small gearwheel (pinion) engaging in the ring gear on the flywheel. Thanks to the large gear ratio between the pinion and ring gear on the flywheel (approx. 15:1), the starter requires only a low torque at high speed. This is why the starters are designed with compact dimensions.

The starter consists of the following assemblies:

- DC starter motor
- Engagement relay
- Meshing gear

Index	Explanation
1	Pinion
2	Solenoid
3	Negative lead
4	Battery positive lead
5	Control wire

By operating the start switch, the engagement relay and the meshing gear mesh the pinion with the ring gear on the flywheel. Following engagement of the pinion, the starter motor turn the crankshaft of the combustion engine with the aid of the pinion and ring gear. The pinion is disengaged as soon as the combustion engine starts up. The various types of starting differ in terms of the way the pinion is meshed or engaged with the ring gear. A pre-engaged drive starter with stepdown gear mechanism is used in BMW vehicles.



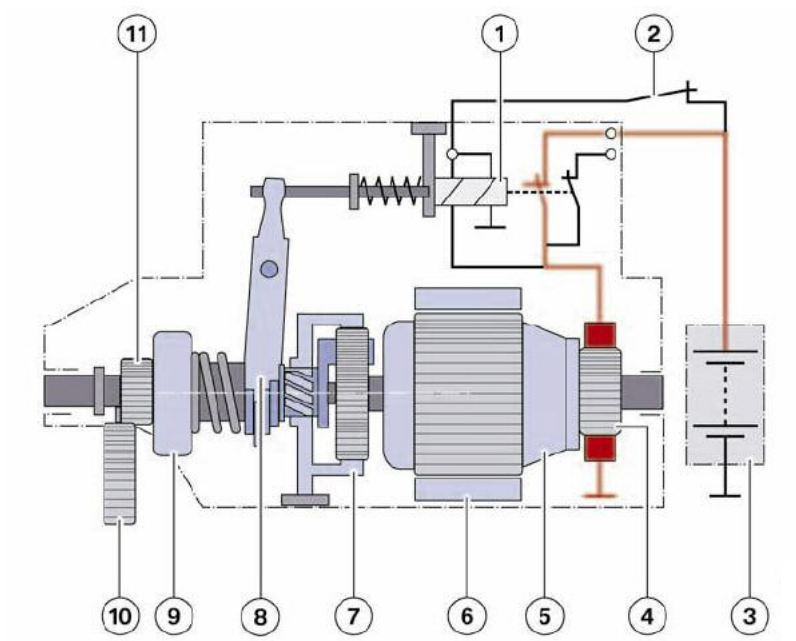
Starter design

Index	Explanation	Index	Explanation
1	Forked lever	7	Rotor (armature)
2	Relay armature	8	Permanent magnet
3	Relay coil	9	Planetary gear
4	Relay spring	10	Sintered ring gear with damping
5	Commutator	11	Pinion
6	Carbon brush	12	Drive bearing

A planetary gear acting as a step-down gear mechanism is installed between the starter motor and the pinion. The planetary gear has the task of reducing the high speed of the starter while simultaneously boosting the torque at the pinion. Since the power output at the starter shaft is proportional to the speed, the power output of the starter can be increased or the dimensions reduced while retaining the same power output levels.

The engagement procedure consists of two partial movements of the pinion:

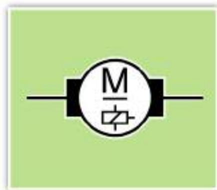
- Translatory (thrust) motion
- Rotary (screwing) motion



Index	Explanation	Index	Explanation
1	Solenoid	7	Planetary gear
2	Start switch	8	Engagement lever
3	Battery	9	Roller freewheeling
4	Commutator	10	Pinion
5	Rotor	11	Ring gear on flywheel
6	Permanent magnet		

After operating the start switch (2), the engagement lever (8) is moved by the solenoid (1). The pinion (11) is shifted forward (sprung) and made to rotate by the coarse pitch thread. If a tooth of the pinion (11) finds a tooth gap, it will engage immediately. If the tooth of the pinion comes up against a tooth of the flywheel (10), the spring on the pinion is compressed until the solenoid (1) switches on the current. The rotor (5) rotates and the pinion (11) slides along the end face of the ring gear (10) until it can engaged.

This graphic symbol is used for the starter in circuit diagrams:



Alternator

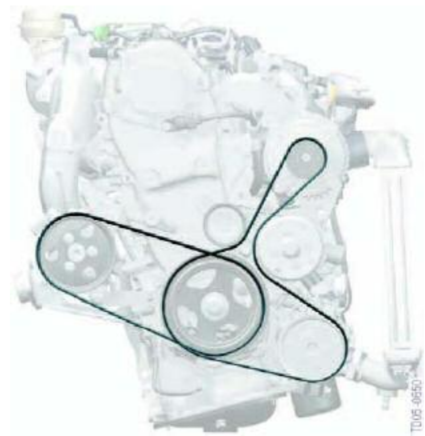
Each vehicle is equipped with its own power station - the alternator.

The tasks of the alternator include:

- To supply electrical loads with electrical energy while the engine is running
- To charge the battery

The first alternators were used in BMW vehicles over 70 years ago for the purpose of supplying power for the electrical lighting.

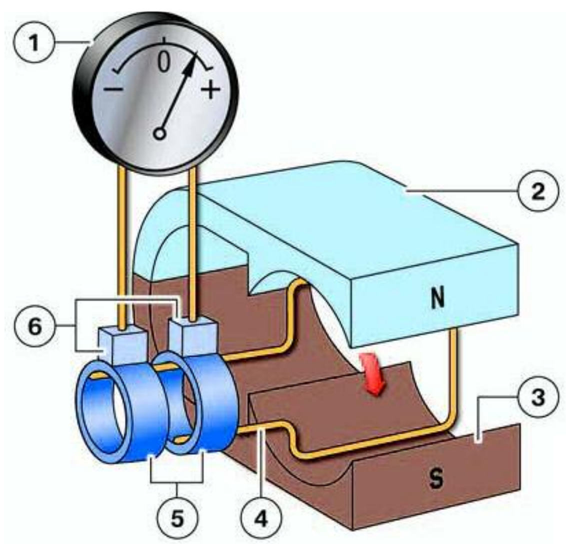
The alternator converts mechanical energy into electrical energy. It is driven by the combustion engine using a V-ribbed drive belt. The alternator is mounted in a fixed position. The required belt tension is achieved with a belt tensioner and tensioning pulley.



Alternator Principle

The functional principle of the alternator is based on the inverse principle of the electric motor. Electromagnetic induction is also the basic requirement for operation of the alternator.

The electrons in an electric conductor are displaced when it is moved in a magnetic field.

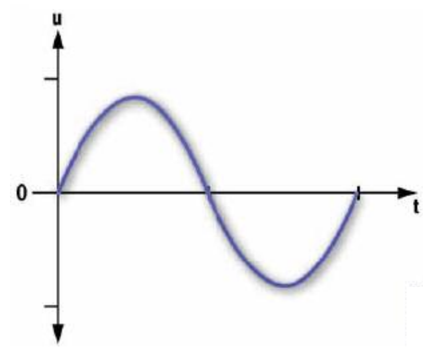


Index	Explanation
1	Voltmeter
2	North pole
3	South pole
4	Conductor loop
5	Slip rings (collector rings)
6	Carbon brush

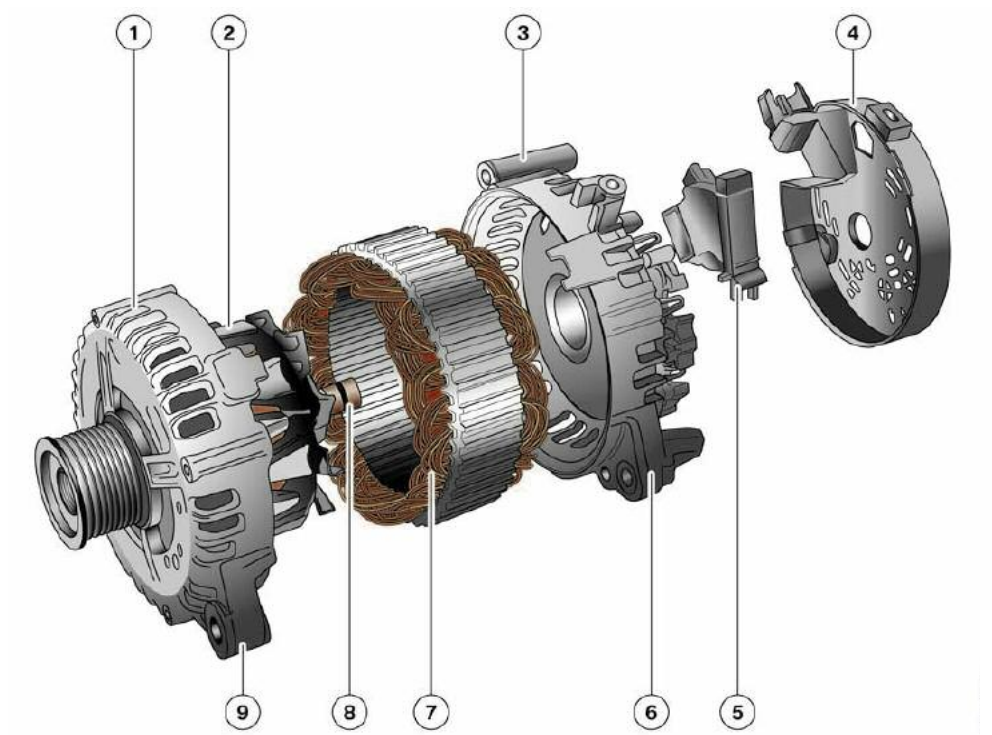
An electric voltage is generated and electric current flows. During the course of the rotary motion, the generated voltage changes its direction (polarity) after every 180°. An alternating voltage is produced.

The magnetic field is produced by electromagnets. The electric loads in the vehicle, the battery and the ignition system, however, require a direct voltage. The generated alternating voltage must therefore be rectified.

Diagram of alternating voltage



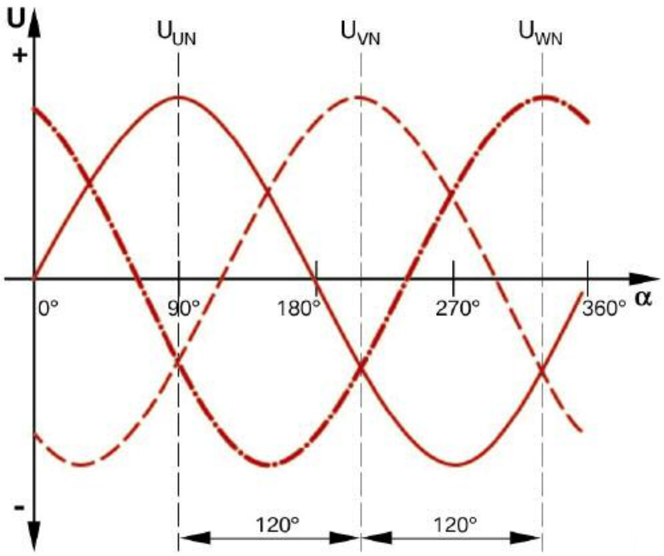
Design and functional principle of the three-phase alternator



Three-phase alternator (exploded view)

Index	Explanation	Index	Explanation
1	Front housing	6	Rear housing
2	Rotor	7	Stator winding
3	Mounting	8	Slip rings (collector rings)
4	Cover	9	Mounting
5	Regulator		

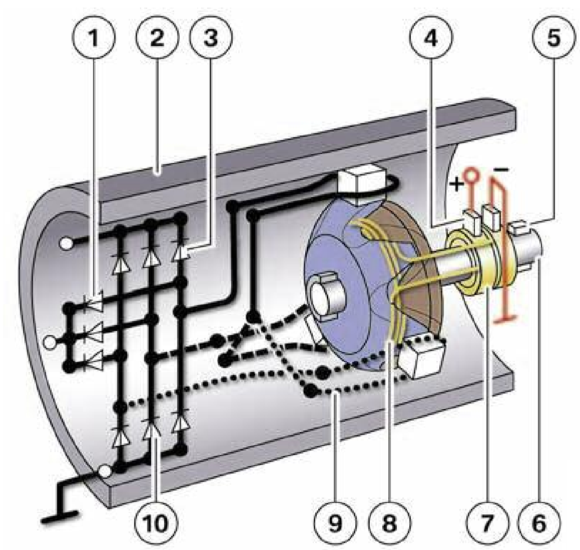
In the stator there are three coils that are connected in "star" arrangement. The beginnings of the coils are identified with the letters U, V, W while the star points are identified with the letter N. The coil terminals are connected to a rectifier circuit. An alternating voltage is generated in each stator coil while the rotor (electromagnet) of the alternator rotates.



Index	Explanation
UUN	Voltage between coil U and star point N
UVN	Voltage between coil V and star point N
UWN	Voltage between coil W and star point N
α	Rotor angle of rotation

The arrangement of the coils in the stator ensures that the three generated alternating voltages are offset by 120° with respect to each other.

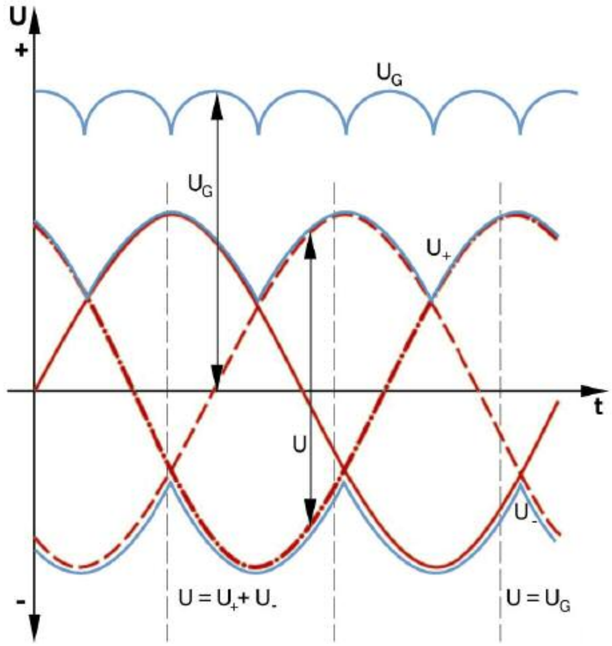
The alternating currents create magnetic fields in the rotor windings whose strength and direction change continuously. The effect of these three magnetic fields together results in a magnetic rotary field.



Index	Explanation
1	Diode trio
2	Housing
3	Positive diodes
4	Carbon brush
5	Bearing
6	Shaft
7	Slip ring (collector ring)
8	Rotor
9	Stator coil
10	Negative diodes

The battery and the electrical system cannot store or use the 3-phase AC voltage produced by a generator, it must be rectified or converted to DC voltage.

A circuit consisting of nine diodes then forms the direct voltage from the alternating voltage.



Index	Explanation
UG	Alternator direct voltage
U+	Positive envelope curve
U-	Negative envelope curve
U	Momentary voltage

Six diodes within diode rectifier bridge are used to achieve three-phase AC voltage rectification. Three diodes are positive biased and three are negative biased.

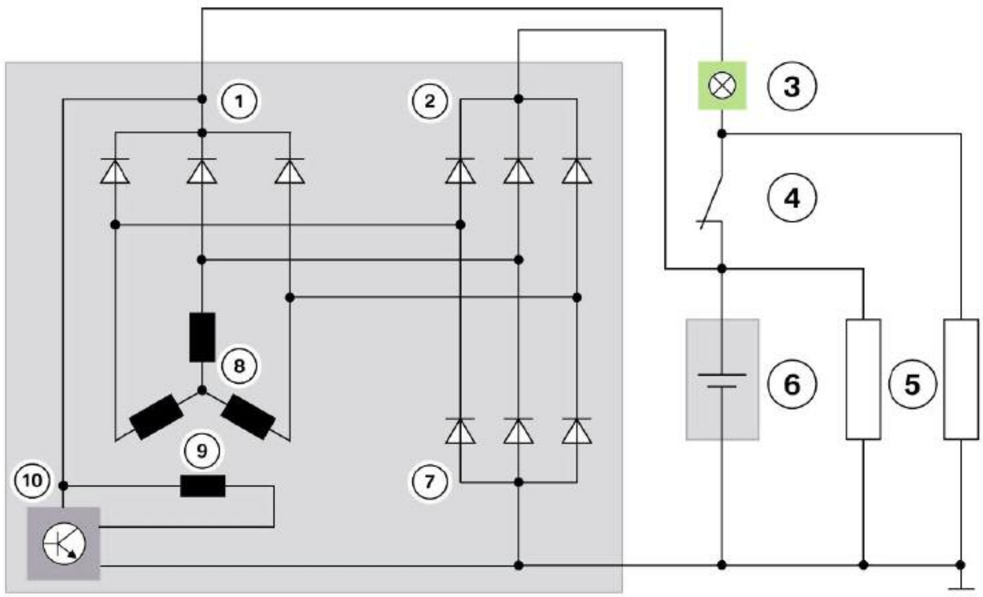
The positive half-waves pass through the positive biased diodes and the negative half-waves through the negative biased diodes.

The rectifier diodes in the generator not only convert the current but also prevent battery discharging through the 3 phase windings of the stator. Current flow can only take place from the generator to the battery.

This direct voltage, however, would be dependent on the engine speed. This means the voltage would be low at idle speed and high at full load. A regulator is therefore installed with the purpose of maintaining a constant voltage. The regulator constantly compares the system voltage with the alternator voltage. The alternator voltage is regulated by changing the strength of the field current. The strength of the field current is not changed as long as the alternator voltage remains at 14 V. If the system voltage drops the field current in the rotor is increased and the voltage rises. However, the combustion engine must use more power to turn the rotor. The field current is interrupted if the alternator voltage exceeds the system voltage.

This graphic symbol is used for the alternator in circuit diagrams:

The following representation is often used to show the inner circuitry of the alternator.



Index	Explanation	Index	Explanation
1	Diode trio	6	Battery
2	Positive diodes	7	Negative diodes
3	Charge indicator lamp	8	Stator coils
4	Ignition start switch (terminal 15)	9	Field coil
5	Electrical loads	10	Voltage regulator

Intelligent Alternator Control

Intelligent alternator control IGR is used in current BMW vehicles. IGR utilizes the previously unused kinetic energy in coasting or overrun mode to drive the alternator. In this way, current is generated and made available to the vehicle electrical system without having to use engine power and therefore fuel. For this purpose, the charge status of the battery must not be full at all times but rather must be within certain limits. When fully charge, a battery can take up no more energy. For this reason, the IGR reduces the charge level. An intelligent sensor at the negative terminal of the vehicle battery as well as a communication interface at the alternator are required for the IGR function.

Note: Intelligent alternator control is described in detail in the F07 Complete Vehicle training material.

NOTES PAGE